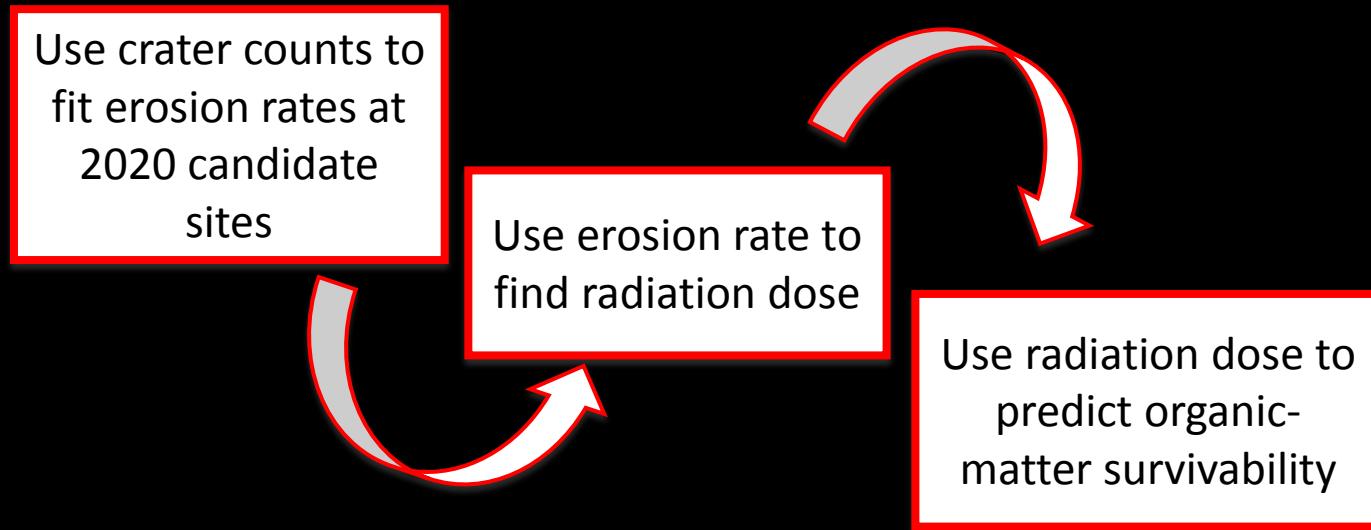


# Crater Count Constraints on Radiolysis of Complex Organic Matter at 2020 Candidate Sites



Edwin Kite

2<sup>nd</sup> Landing Site Workshop for the  
2020 Mars Rover mission

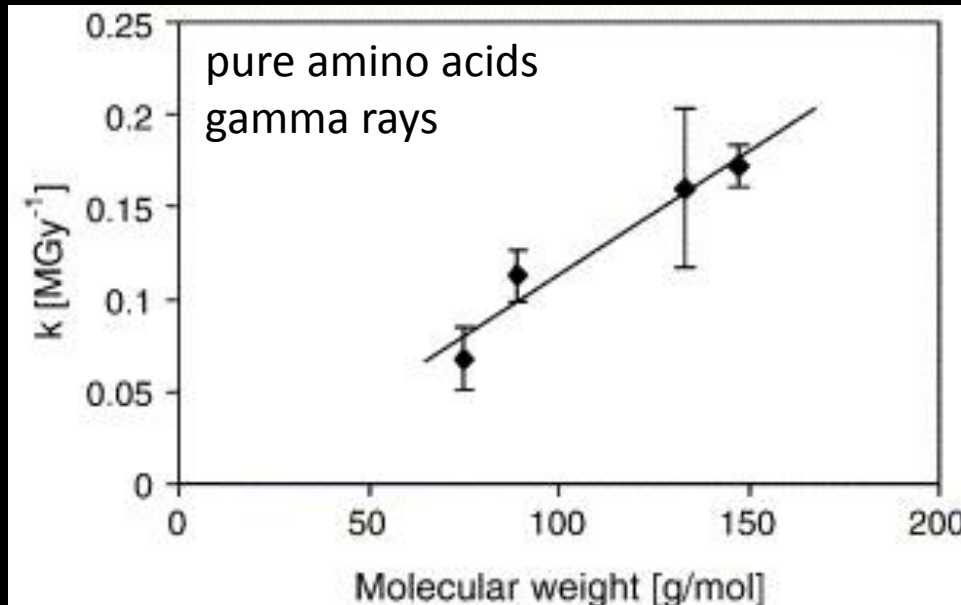
4 August 2015



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# Rapid exhumation mitigates a significant concern for preservation of complex Mars organic matter: radiolysis

Simple amino acids are degraded in < 100 Myr.



*Kminek & Bada, EPSL, 2006*

e.g. **Eigenbrode et al., AbSciCon 2015**

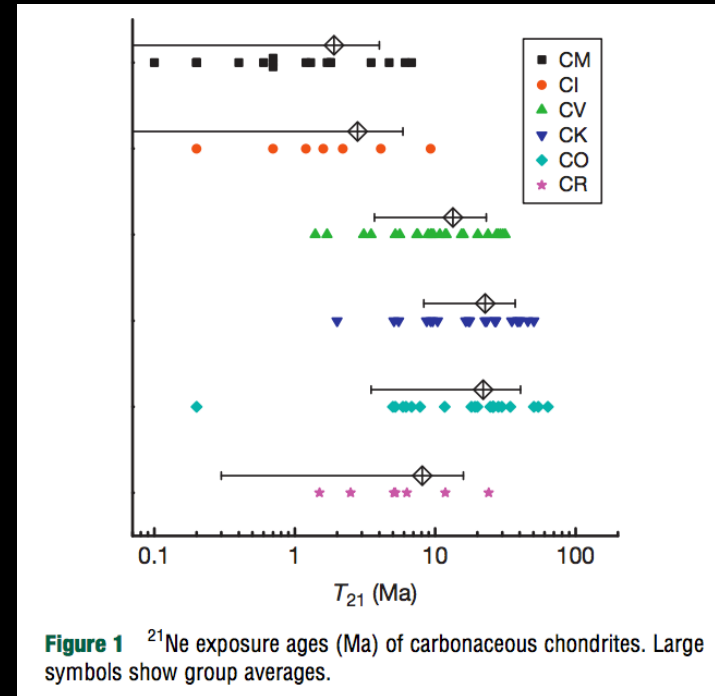
Pavlov et al., AbSciCon 2015

Pavlov et al., GRL, 2012

Kminek & Bada, EPSL, 2006

Gerakines et al., 2012 ...

Amino-acid bearing meteorites have << 100 Myr exposure ages.

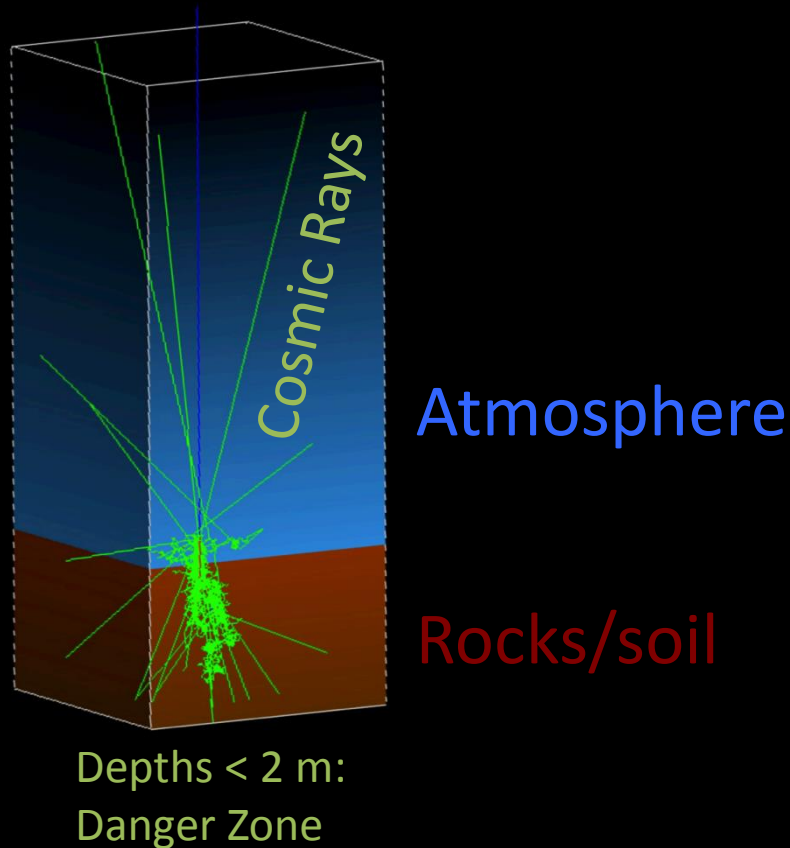


*Herzog & Caffee, Treatise Geochem., 2013*

Simple organic matter in old Mars materials is hard to interpret given the high flux of Mars-crossing organic-rich bolides >3.3 Ga

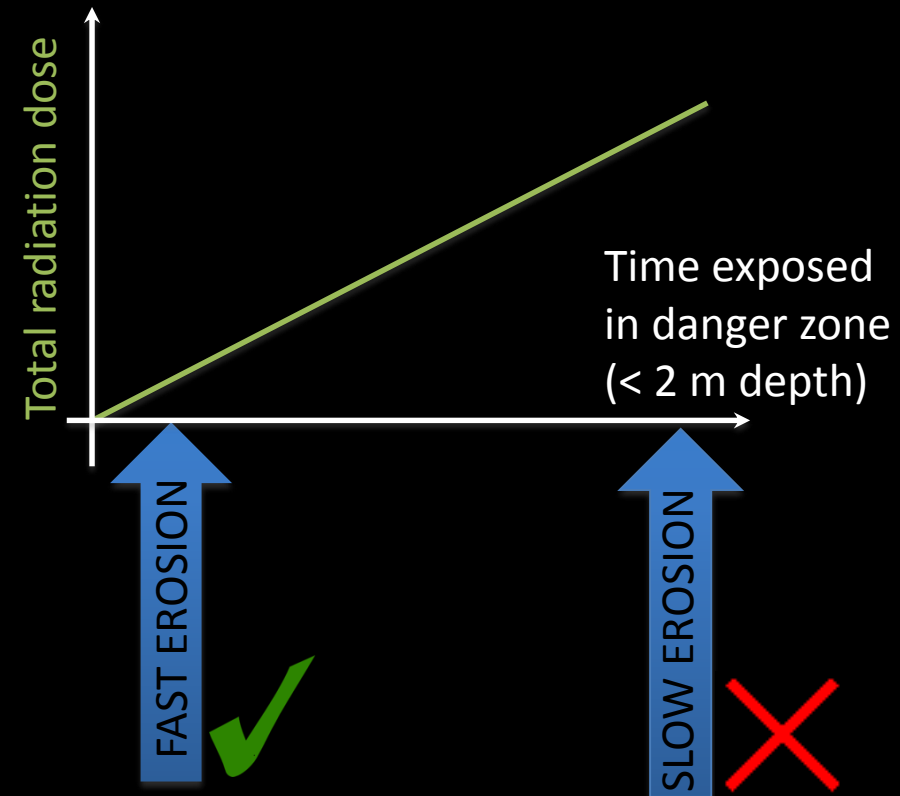
# Rapid erosional exhumation minimizes radiolysis of complex organic matter

Galactic cosmic rays destroy life evidence in rocks exposed near Mars surface for long periods



*Dartnell et al. Geophysical Research Letters 2007*

Fast-eroding rocks are exposed near surface for a short time, avoiding cosmic ray destruction of life evidence



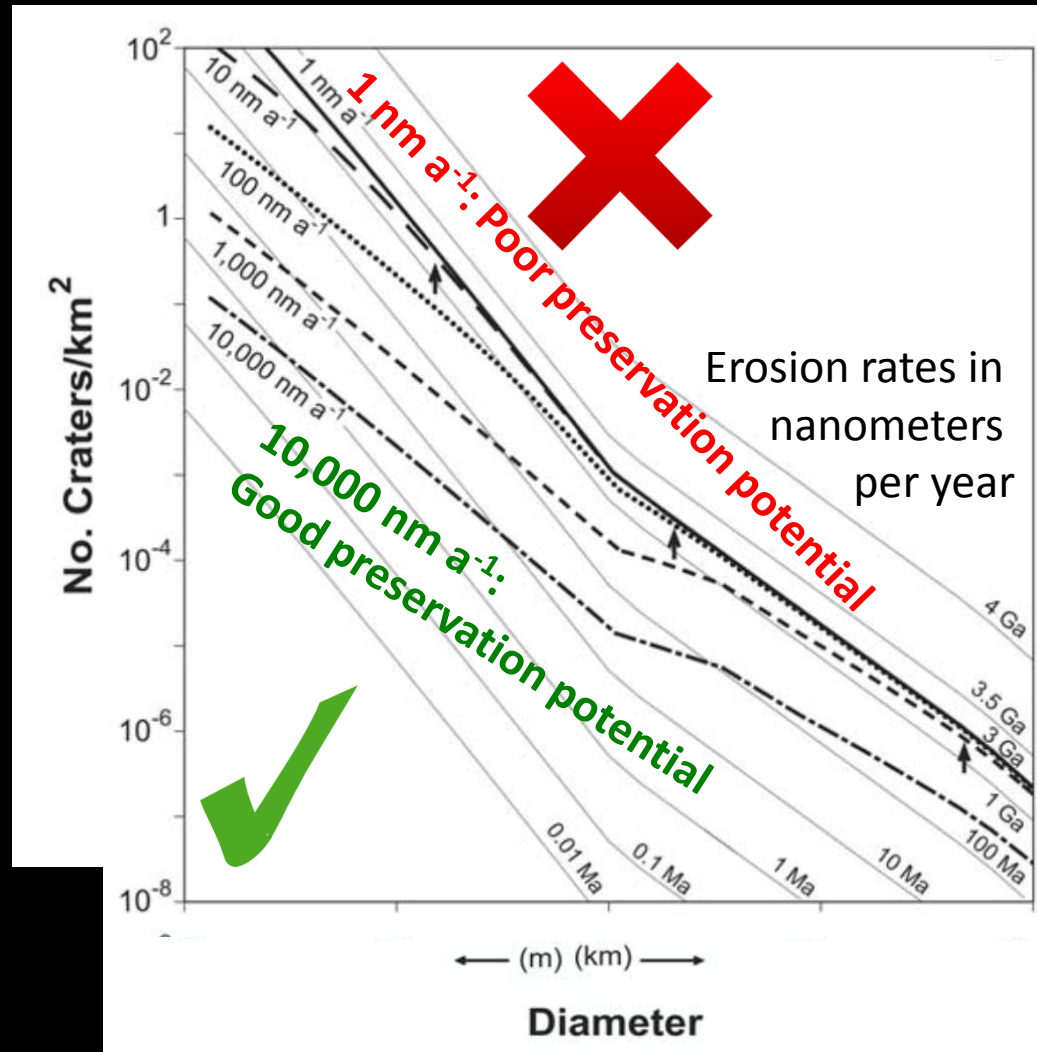
Erosion moves rocks up relative to surface  
Fast Erosion = less time spent  
in the danger zone

# How can we remotely identify regions of rapid exhumation?



Farley et al., Science 2014  
Rice, next talk

# Preservation Potential of Mars Rocks can be Measured by Crater Counts



Smith et al. (2008) *Geophysical Research Letters*



## Crater counts constrain exhumation rate → organic matter preservation potential

$\dot{z}$  = erosional exhumation rate (from fits to crater counts).

- Only independently-identified craters fitted (3-5 counters per image).
- Hartmann (Icarus, 2005) crater chronology – fit to a steady-exhumation rate  $\dot{z}$ , which better represents crater size-frequency distributions for Mars sedimentary rocks than does a single resurfacing age (Smith et al. GRL 2008; Kite et al. Icarus 2013; Kite et al. Nature Geoscience 2014).

$$R \approx \int a e^{-bD} dt = \int a \exp(2b - 2b\dot{z}t) dt = \frac{a \exp(bt\dot{z}) \exp(-2b)}{b\dot{z}}$$
$$\Omega \approx \exp(-k(M_{amu})R)$$

$\Omega$  = fraction of organic matter surviving radiolysis.

$R$  = radiation dose.  $D$  = depth below surface (declines due to exhumation  $\dot{z}$ ).

$b$  = decay constant for radiation absorption by rocks/soil.

$k$  = radiolysis (decay) constants.  $M_{amu}$  = molecular mass of organic matter.

- SCR neglected – GCR only. Dry heterogeneous regolith.
- RAD-measured radiation dose (Hassler et al. Science 2014)
- Exponential fit to Dartnell et al. (GRL, 2007) radiation decay profile (omission of Pfozter maximum is OK for steady exhumation)
- Kminek & Bada (EPSL, 2006) radiolysis (decay) constants; see also Pavlov et al. (GRL, 2012).

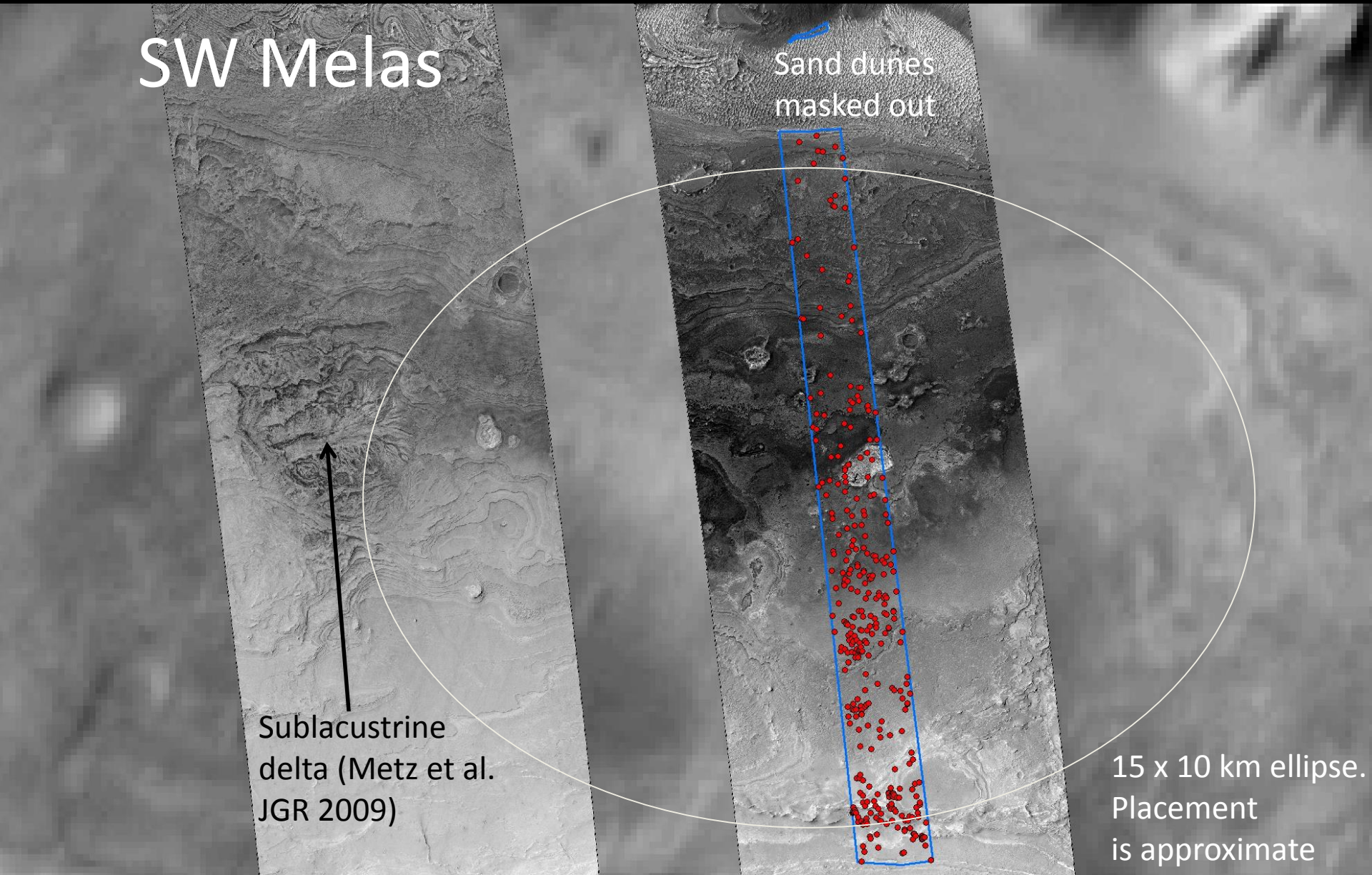
# SW Melas

Sublacustrine  
delta (Metz et al.  
JGR 2009)

Sand dunes  
masked out

15 x 10 km ellipse.  
Placement  
is approximate

ESP\_019508\_1700 counted. Red dots: craters. Blue polygon: Count area.



# Crater-Count Exhumation Rates

Crater Diameter (km)

$10^{-2}$

$10^{-1}$

Crater-Obliteration Rate (m/yr)

$10^{-6}$

$10^{-7}$

$10^{-8}$

$10^{-9}$

SW MELAS CHASMA

Effect of  
maximizing  
obliteration  
depth fraction

slope for  
steady exhumation

slope for single  
resurfacing event

Diameters < 7m not included in fit

# Taphonomic Implications

Organic Matter Surviving Radiolysis

100%

50%

0%

50%

100%

500 amu

113 amu

x0.5  
decay  
constant

effect of  
very  
weak  
target  
rocks

Yellowknife Bay  
(Farley et al.  
Science 2014)

Equivalent Steady Exhumation Rate (m/yr)

$10^{-6}$

$10^{-7}$

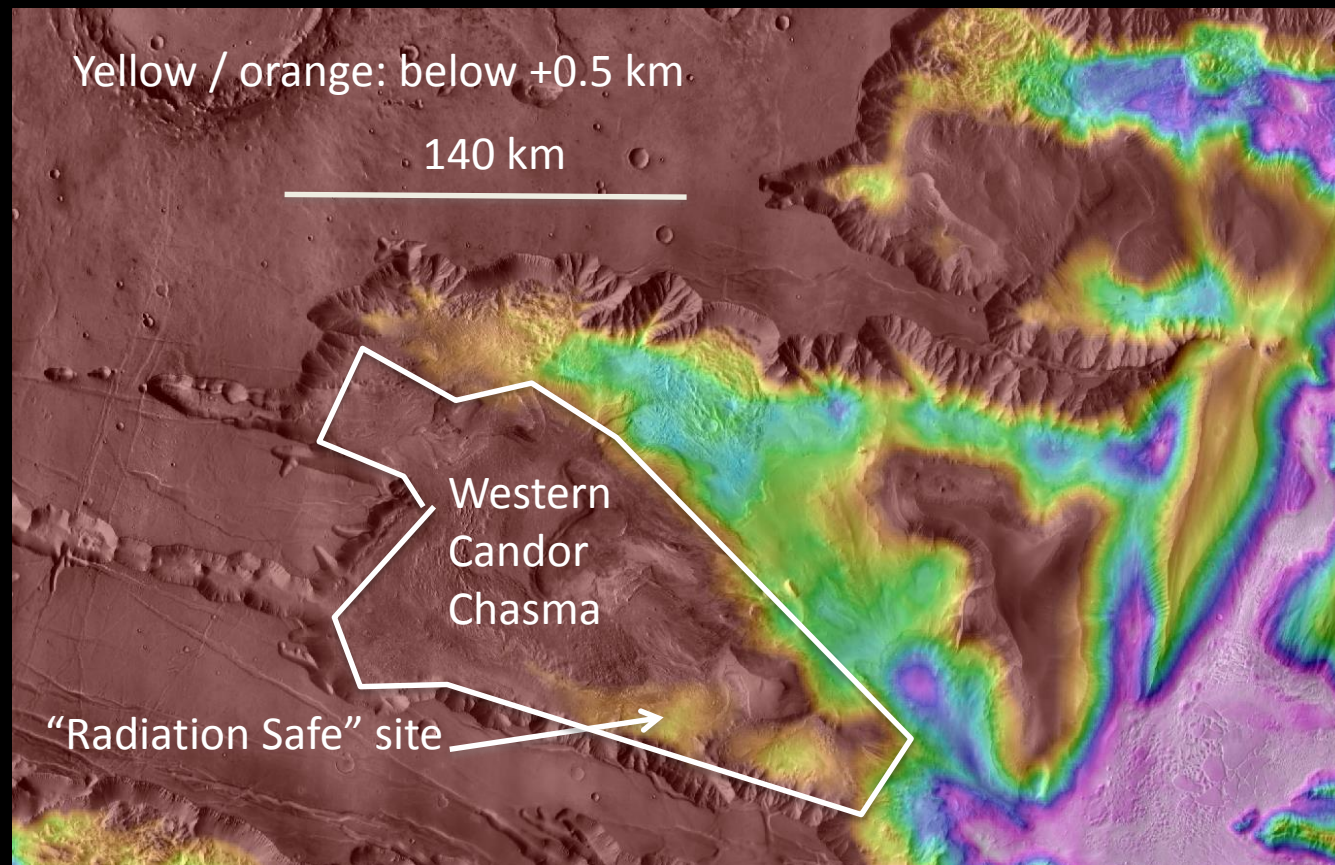
$10^{-8}$

$10^{-9}$



# W Candor (“Radiation Safe”) site

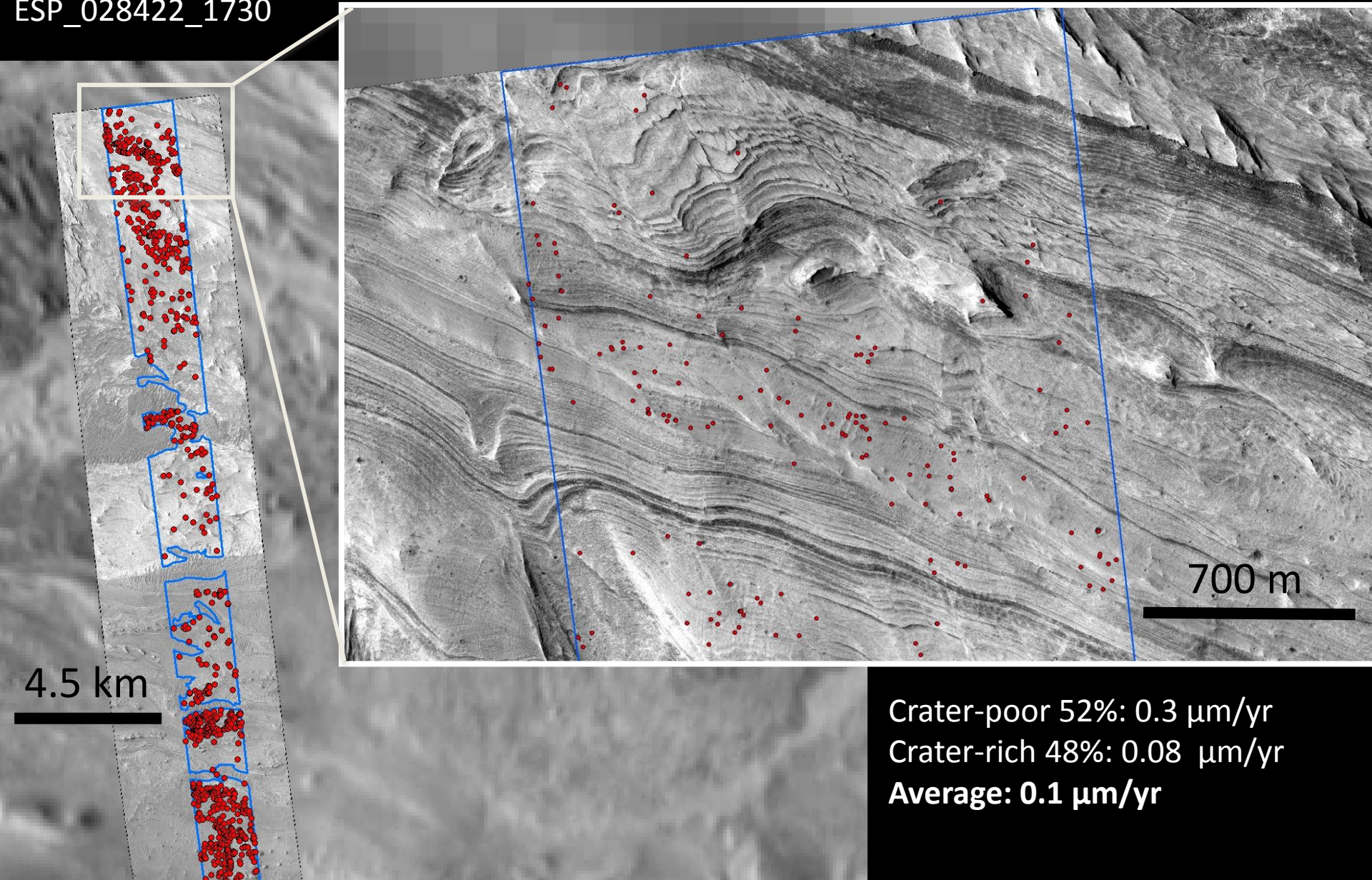
Rationale: “the extreme paucity of impact craters on the surfaces of exposed, light-toned layered rock outcrops [...] is best illustrated in western Candor Chasma” - *Malin et al. JGR 2007*





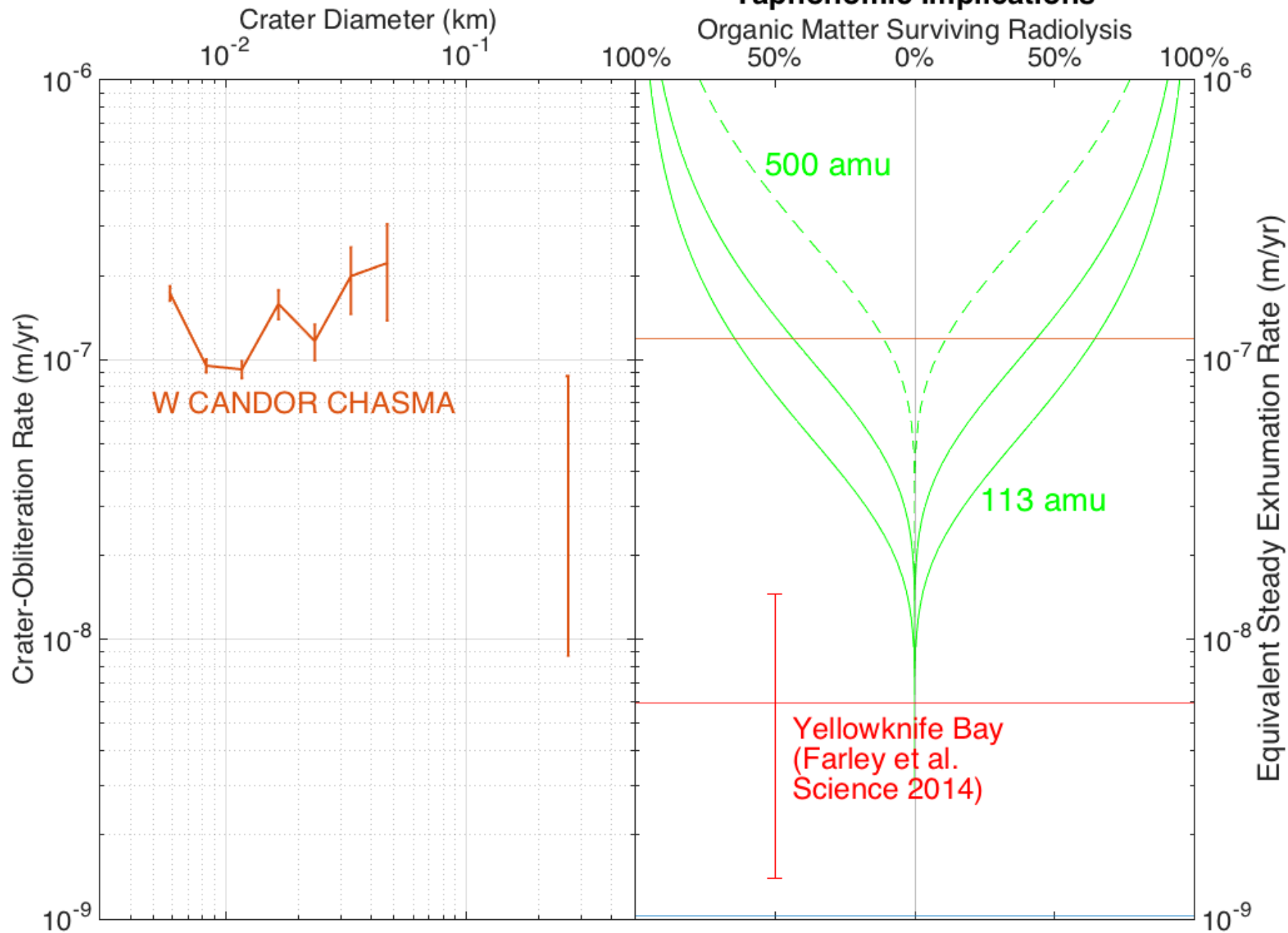
# W Candor ("Radiation Safe")

ESP\_028422\_1730



## Crater-Count Exhumation Rates

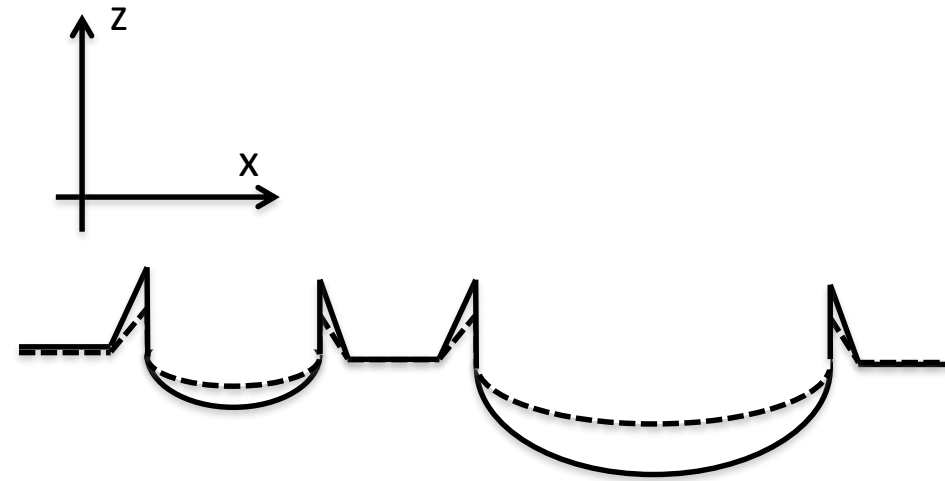
## Taphonomic Implications



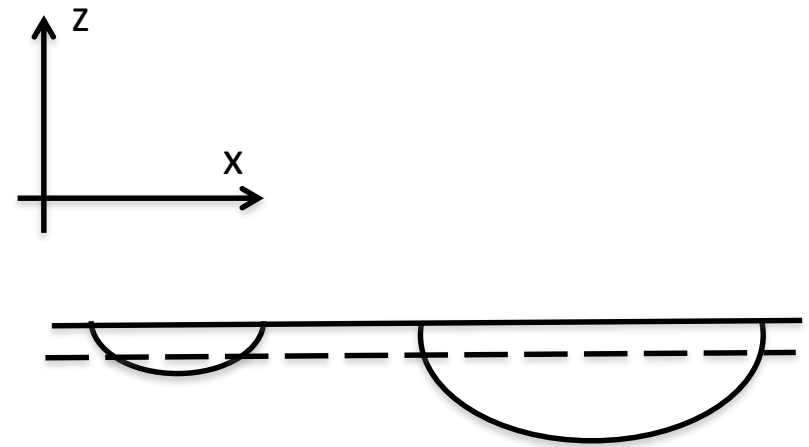


**Caveat!** Crater size-frequency distributions can exclude rapid exhumation, but cannot prove rapid exhumation.

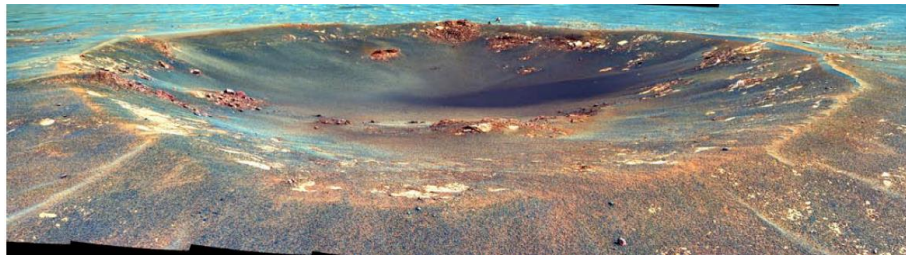
- 'Minus 2' slope can mean diffusion or exhumation



Poor organic-matter  
preservation potential  
in inter-crater terrain



Landscape-lowering  
Good organic-matter  
preservation potential

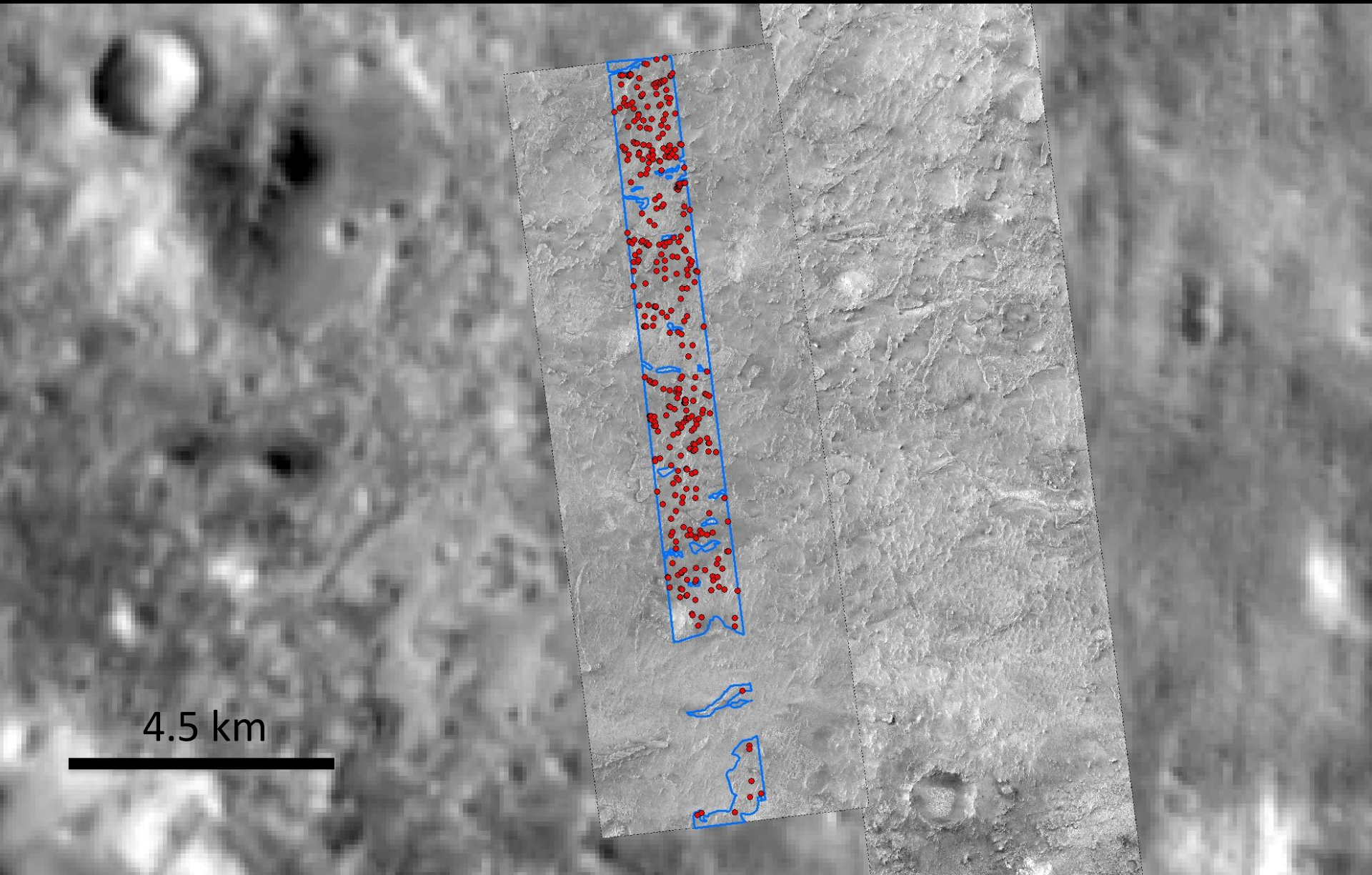


Example:  
16m-diameter crater  
Golombek et al. JGR-E 2014

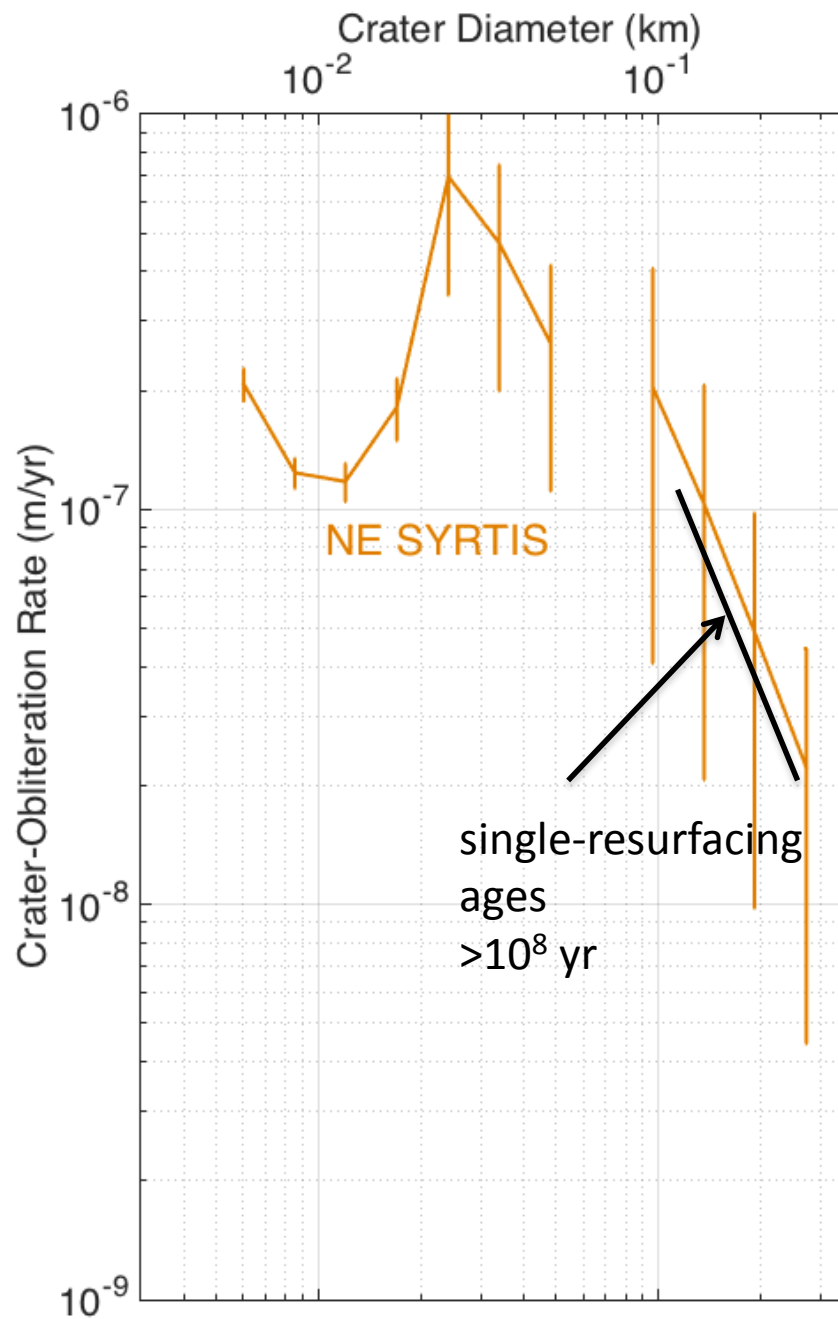


# NE Syrtis Major

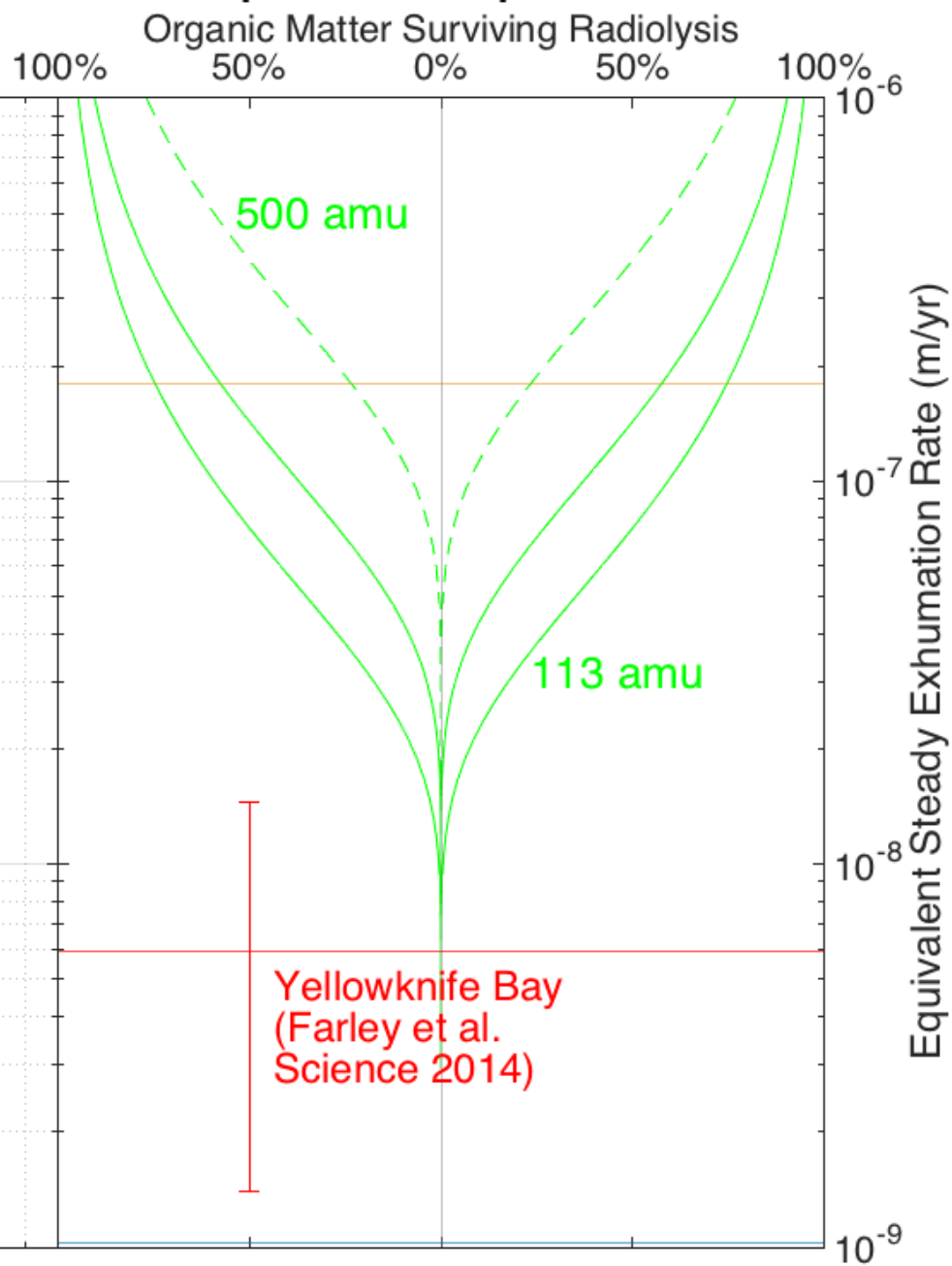
ESP\_015942\_1980: Near center of ellipse



## Crater-Count Exhumation Rates



## Taphonomic Implications



# Conclusions

- **All sites studied are on the cusp of complete destruction of complex organic matter via radiolysis.**
  - Few published radiolysis constants are available.
  - Additional Mars-relevant radiolysis constants would be valuable.
  - Craters 10-20m diameter are the most valuable for constraining radiolysis.
  - No strong reason to choose between the sites studied on the basis of terrain-averaged organic-matter survivability against radiolysis.
  - Downward revisions to crater flux (Daubar et al. 2013) would reduce preservation potential.
- Radiolysis is an *e*-folding process, and **factor-of-a-few differences in erosion rate (around the “Mars average” for sedimentary rocks) can make the difference between complete destruction and complete retention of complex ancient organic matter.**

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Thanks to summer RAs: Emily Thompson, Daniel Eaton, William Misener, Chuan Yin, Edward Warden, Julian Marohnic; and to Planetary GIS/Data Specialist David Mayer.

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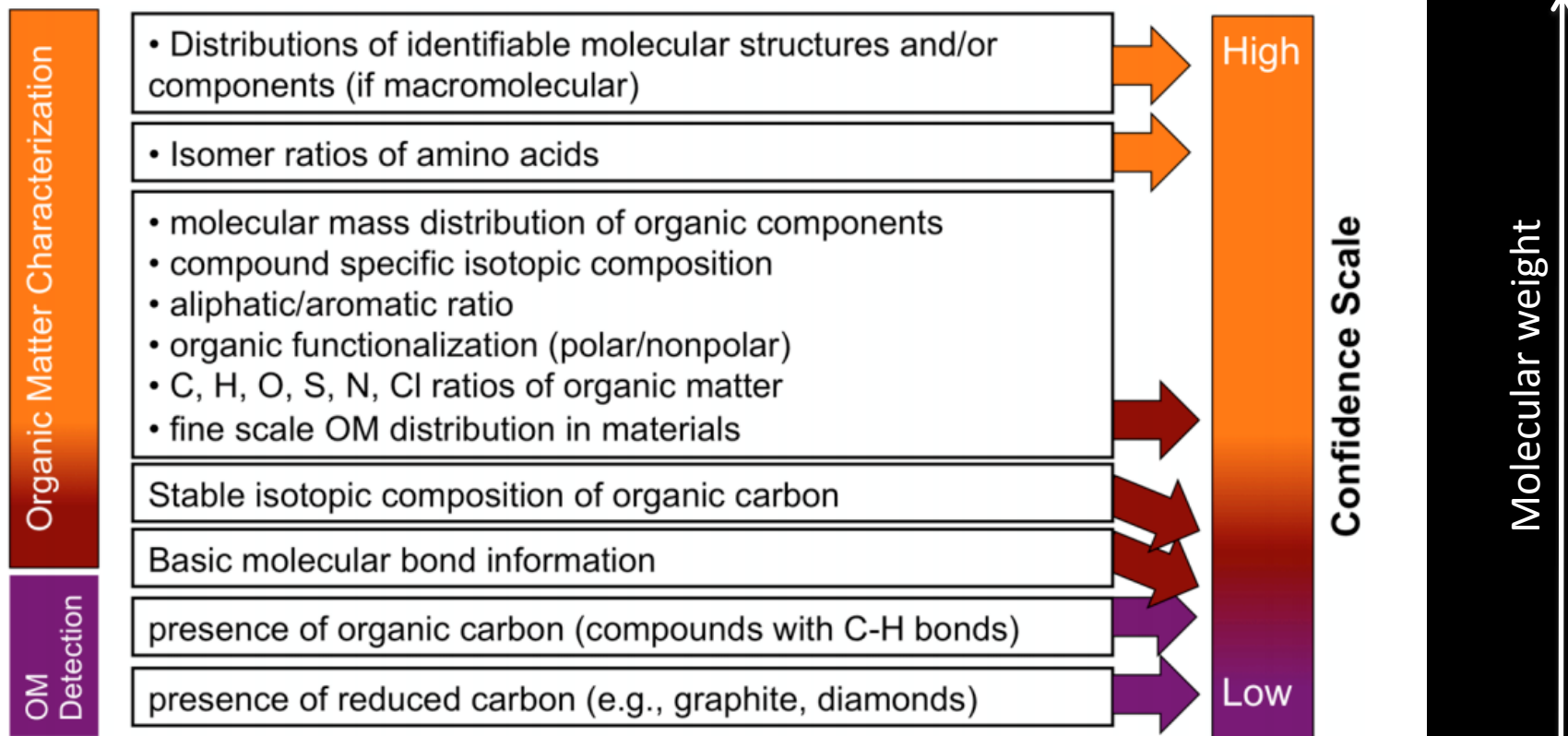
[planetarygeoscience.uchicago.edu](http://planetarygeoscience.uchicago.edu)



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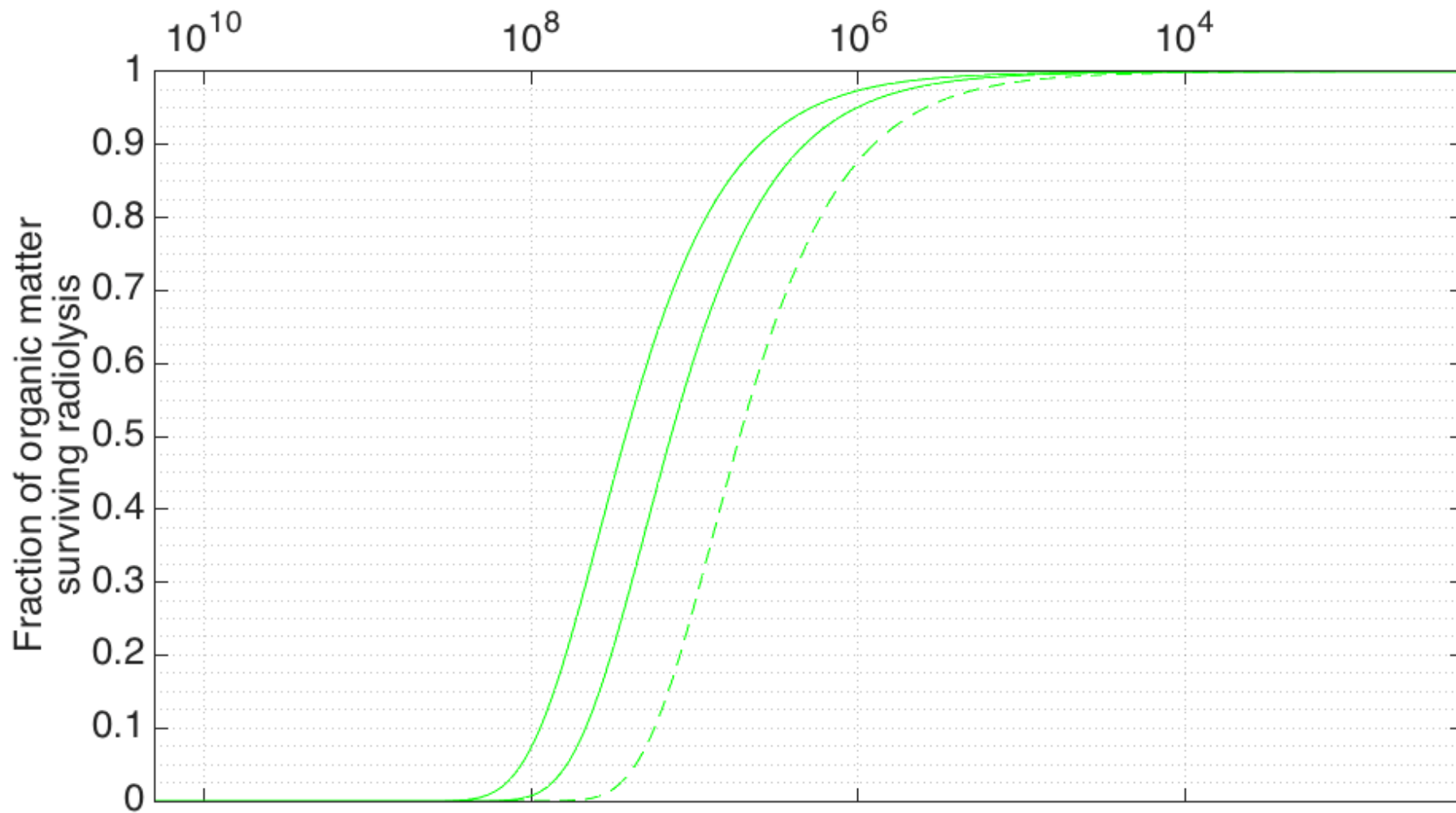
# Supplementary Slides





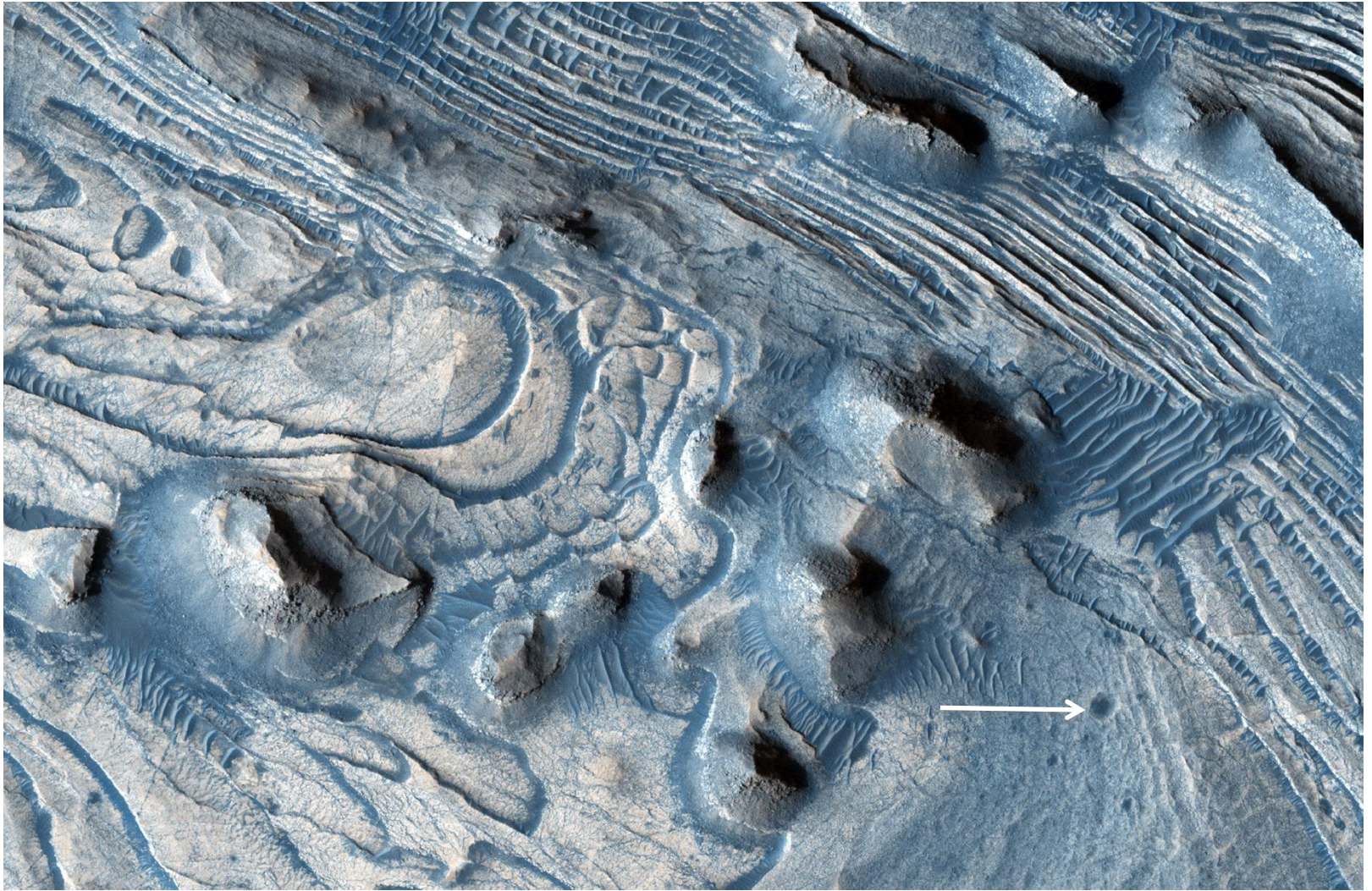
**Figure 3-14. Organic molecule detection methods are not as definitive as some types of organic matter characterization.** Confidence of detecting or not Definitive Biosignatures (DBS) for various observation types about organic matter (OM). Observation types in central column, arranged in order of confidence that the observation could yield a definitive biosignature (right column). Left column denotes general type of the observation: detection vs. characterization of the organic matter. Note that the level of confidence provided by a given measurement varies depending on the specific details (e.g. degree of thermal degradation) of the sample being investigated.

years in exhumation zone





# Wind-Erosion Speedometer



# Erosion Speedometer

*Smith et al., GRL 2008*

*Kite, Lucas & Fassett,*

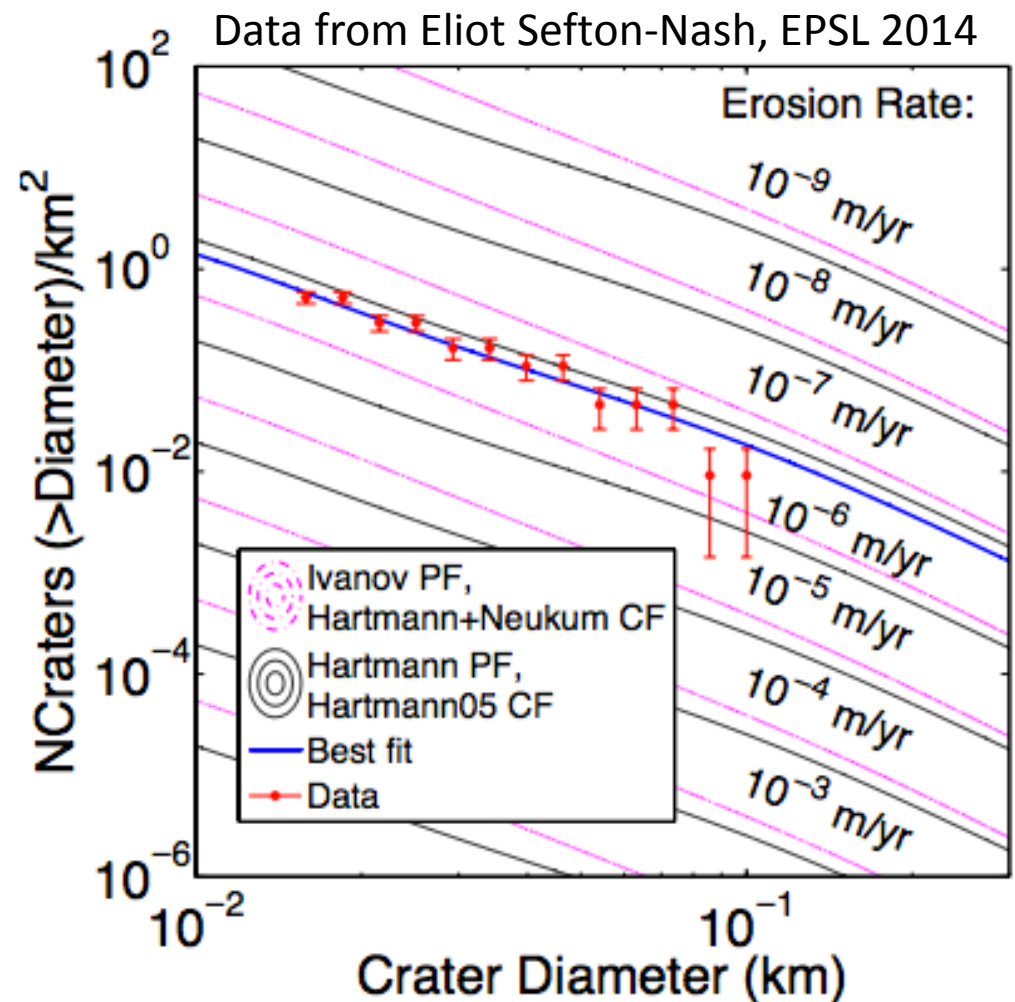
*Icarus 2013 (4-page 'Note')*

*Kite, J.-P. Williams, et al.,*

*Nature Geoscience 2014*

Absolute calibration through cosmogenic  
radionuclides:

*Farley et al., Science 2014*



$$p(Y|D, P) = \bar{\lambda}^Y \exp(-\bar{\lambda}) / Y!$$